The AXION Experiment

How the instrument was designed in 1992
And the Squid upgrade plan.

Wolfgang Stoeffl Aug 25 2015 Proposal (New) for Physics Exploratory Research in the Disciplines

SEARCH FOR PSEUDOSCALAR COLD DARK MATTER

Principal Investigators:

Karl van Bibber (E-Div.), Wolfgang Stoeffl (Nucl. Chem.)

LLNL Collaborators:

P.L. Anthony (E. Div.), R.E. Patrick, D.S. Ravenscroft, S.S. Shen, D.S. Slack, S.W. Ferguson (MFE Prog.)

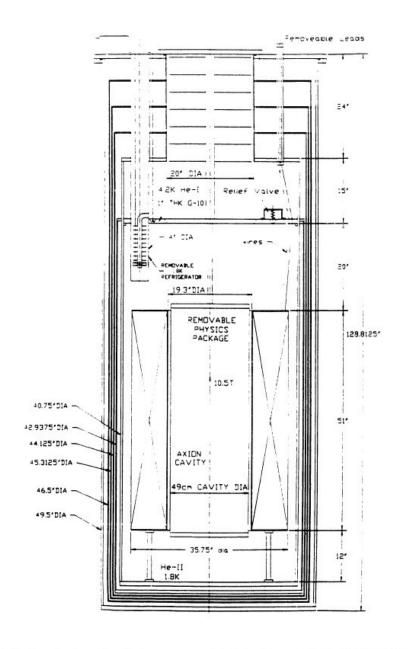
Collaborating Institutions:

University of Florida
Institute for Nuclear Research of the Russian Academy of Sciences
Massachusetts Institute of Technology
University of Chicago
Fermi National Accelerator Laboratory
Lawrence Berkeley Laboratory
University of California Berkeley
Stanford Linear Accelerator Center
Wang NMR, Inc.

May 29, 1992





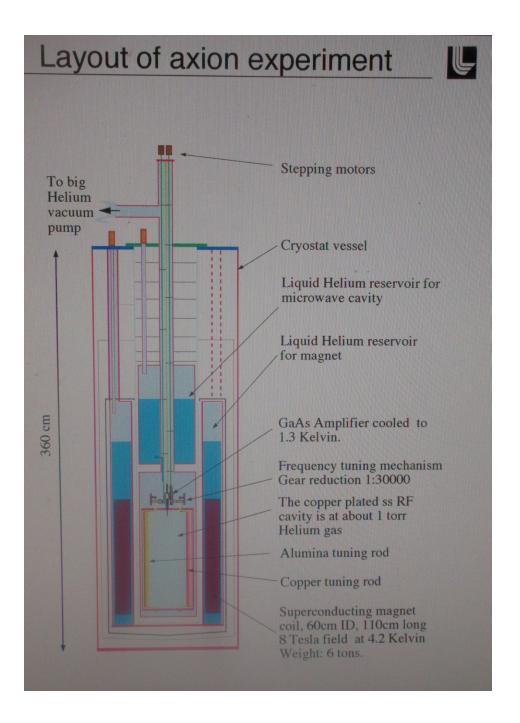


We looked for available BIG magnets

The Axicell magnets of the MFTF-B Were considered. > Too big

The NASA SUMMA magnets were a better contender. But flooding the whole system with superfluid helium is impractical, and no access the cavity and electronics without warming everything up.
Way too time consuming.

Figure 3. Design of a thermally efficient cryostat, and 1.8 K refrigerator for the NASA SUMMA coils.



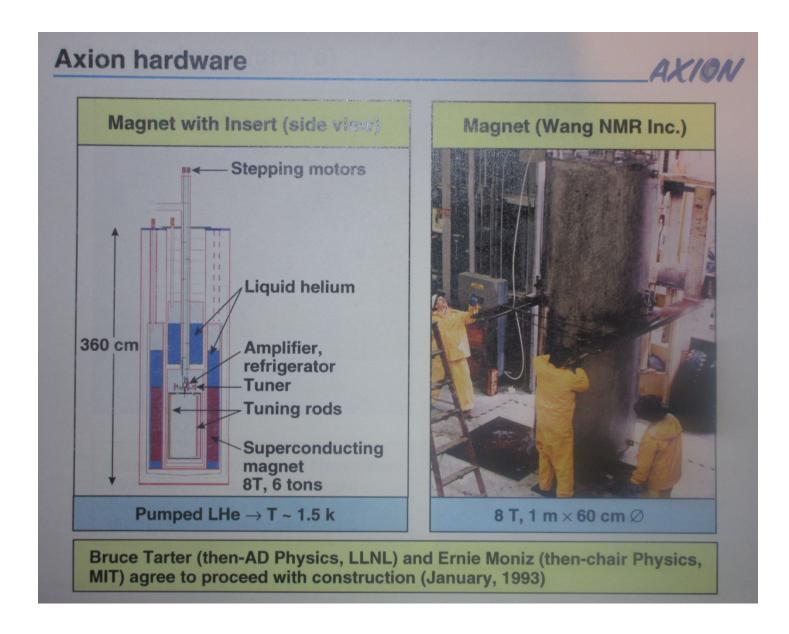
Then the present design emerged, with efficient use of Helium,
The cavity can be lifted out without warming up the magnet.

The overall height of the cryostat was dictated by the freeway bridges and the door into the LLNL building.

Wang NMR in Livermore built a new 8 Tesla magnet to spec.

A few facts:

Superconducting coil weighs 6 tons. Hoop force in the coil is 1200 tons. Compressive force in the midplane is 800 tons.

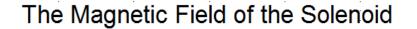


The 11 ton magnet was delivered in pouring rain...

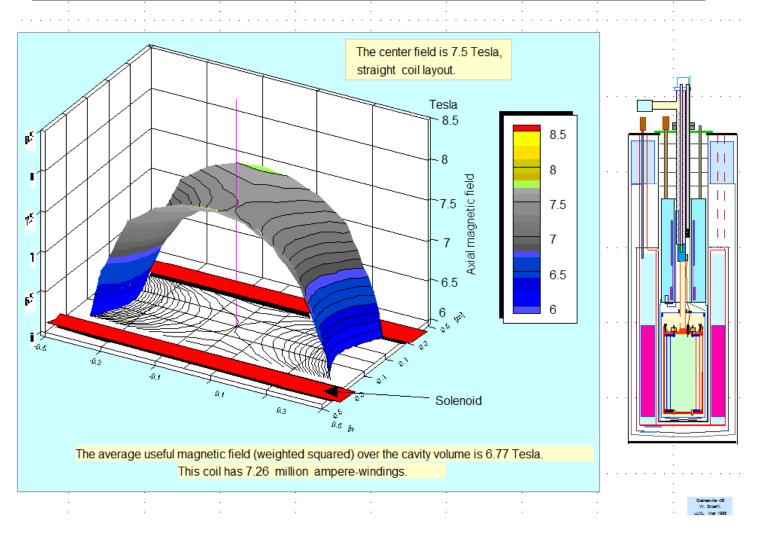
And it survived the old railroad crossing at 55 miles per hour!



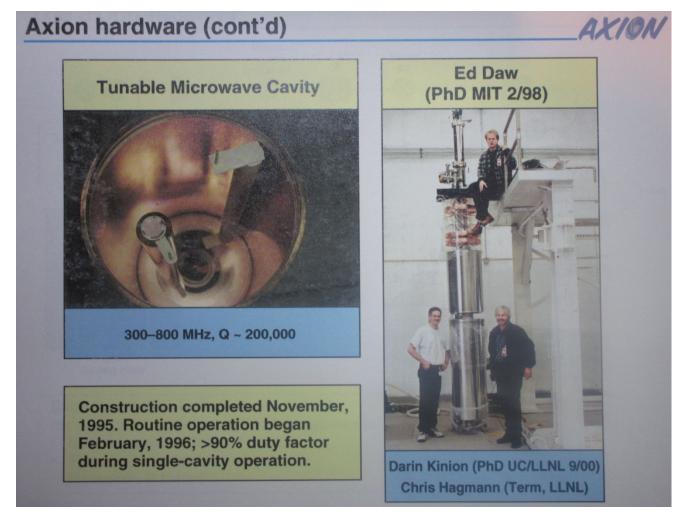
The Livermore riggers lower the magnet into the tight fitting pit. No access to the high field, no hazard...







The magnetic field if a straight solenoid is NOT flat. But it is the best configuration to maximize the Axion signal.



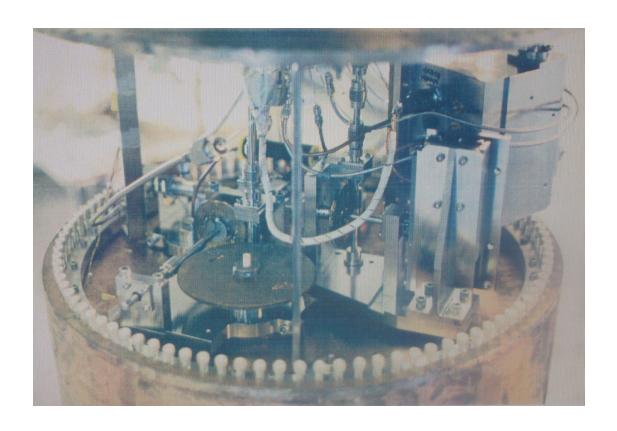
The two tuning rods to steer around mode crossings

The cavity tower

Starting in Feb 1996, the Axion experiment ran at 1.2 Kelvin uninterrupted for more than a year, and then with 90% data time.

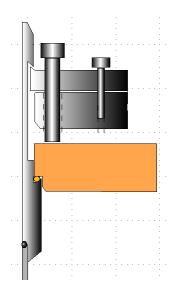
The cavity is made from SS316 and a thin UBAC organic and annealed copper coating. A magnet quench would destroy a copper or aluminum cavity or thermal shield.

We built the Axion experiment from start of funding to data taking in about 18 months.



The big cavity had a warm stepping motor driven anti-backlash gear drive.

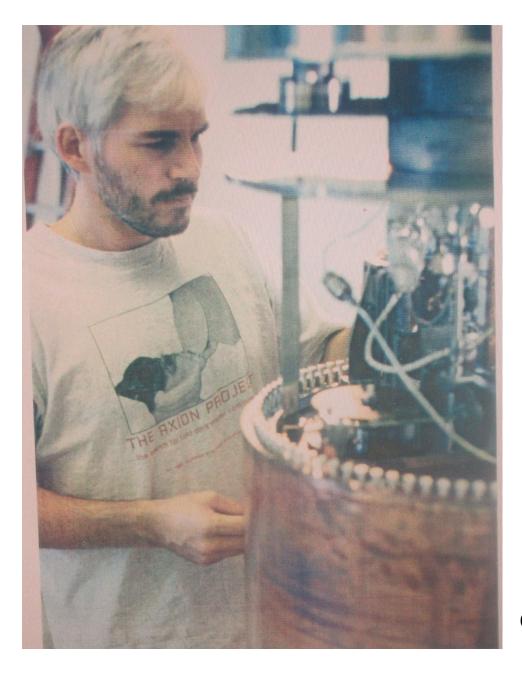
Need to run the gears while cooling down!
Otherwise one has H2 ice crystals on the gears.
It worked....



The huge compression force in the top cavity flange is needed to crush the copper oxide later.

Otherwise the Q is nowhere near the 250000 we achieved.

The antenna insertion is motorized to keep it at 50 Ohm



Chris designed our AXION T-shirt.

1.3 Mechanical/Cryogenics — Plan of Work



The Mechanical/Cryogenics tower for the Phase I upgrade is very similar to that of the present experiment (built FY94-95). Both are 1.3 K pumped LHe systems, with similar geometry

For the present experiment (FY94-95):

- · W. Stöffl did all Engineering
- J. Dressler did all Mechanical Design
- Physicists did all Assembly and Testing
- · W. Stöffl did preliminary design for the magnet
- Wang NMR built the magnet

We will do exactly the same for the Phase I upgrade.

The present experiment is an excellent benchmark for it.

W. Stöffl's participation brings high confidence of success.

It was a long time ago...... already planning for the upgrades.

Axion Collaboration

D. Kinion, W. Stoeffl, K. van Bibber, C. Hagmann *LLNL*

E. Daw, J. McBride, H. Peng, L. Rosenberg, H. Xin *MIT*

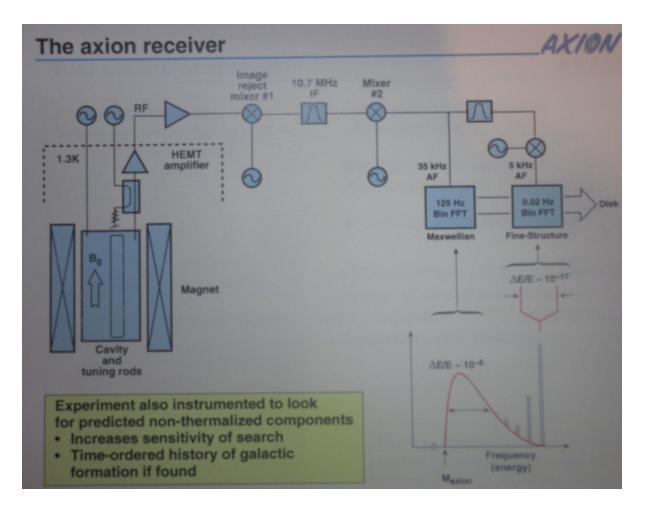
P. Sikivie, N. Sullivan, D. Tanner *University of Florida*

D. Moltz Lawrence Berkeley Laboratory

F. Nezrick, M. Turner Fermi National Accelerator Laboratory

N. Golubev, L. Kravchuk Institute for Nuclear Research of the Russian Academy of Sciences

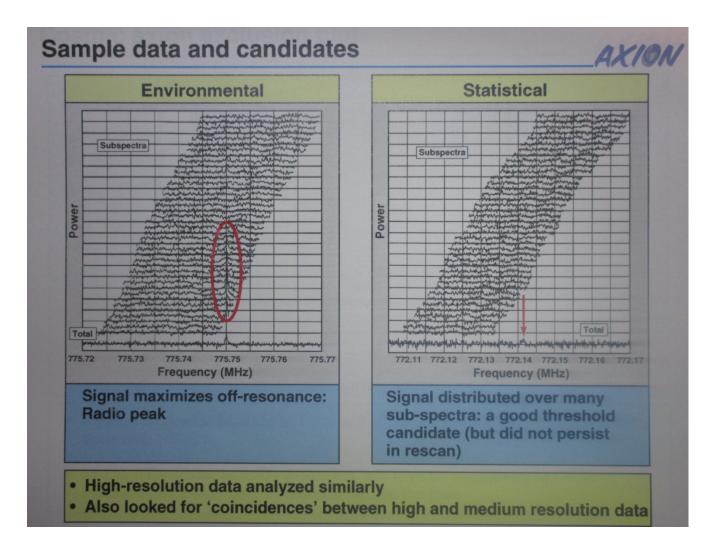
The early AXION Collaboration.



MIT built the microwave Heterodyne receiver system.

The Q-resonance scan is done just before each scan with a network analyzer, to keep the 100 kHz bandpass filters and FFT on center.

We also built the Megachannel FFT to search for narrow AXION signals. 0.01 Hz resolution at 700 MHz.



Darrin Kinion was the master of Labview programming.

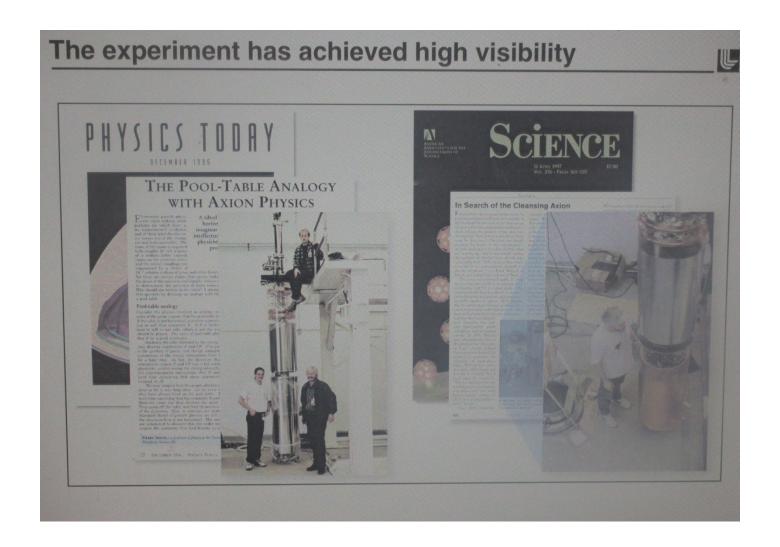
We slowly scanned the frequency and summed up the spectra.

A real Axion signal has to follow the Q-curve, noise is off-Q

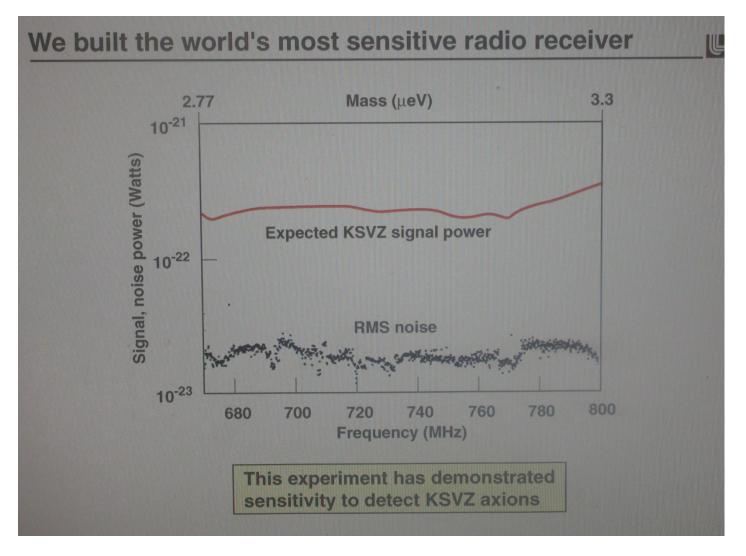
(statistical) Candidates above a sigma of 2.7 were rescanned to optimize scan rate.

A real Axion has to vanish with B=0.

We saw quite a few radio sources and other atomic clocks!



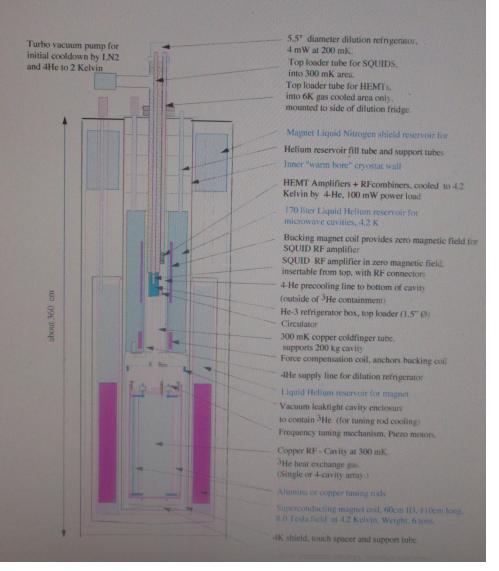
We got a lot of publicity mileage out of the early data runs.

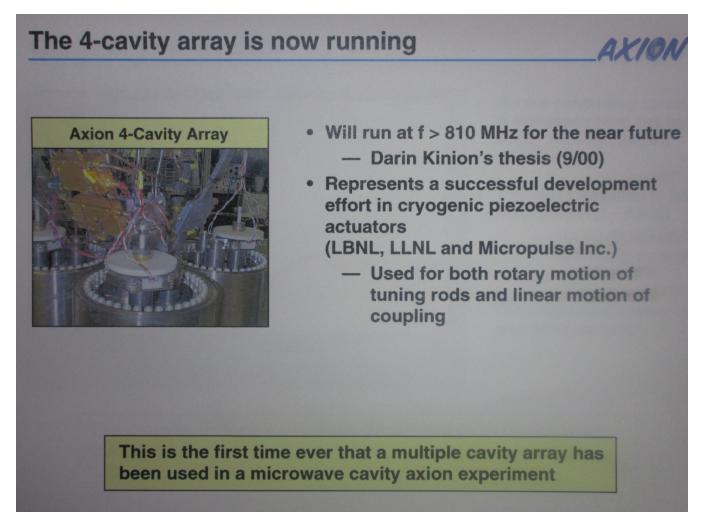


A proud achievement

The SQUID Axion Experiment

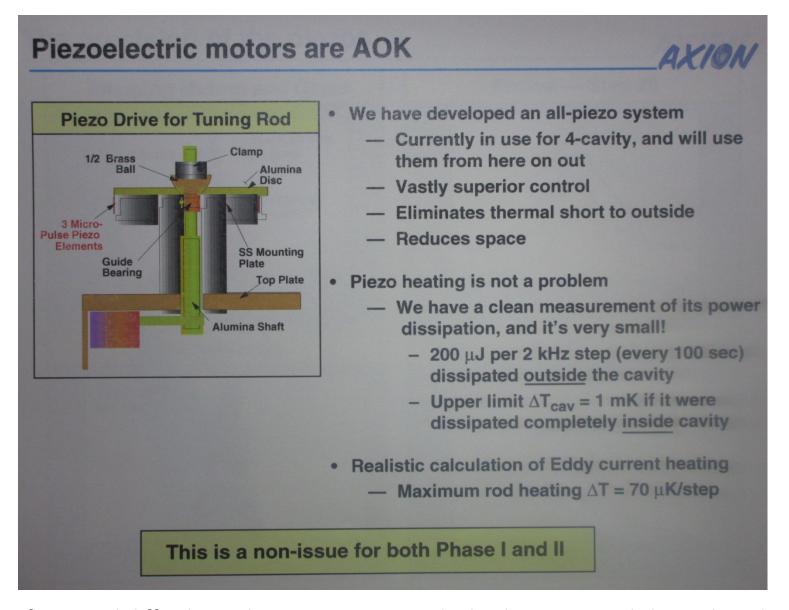




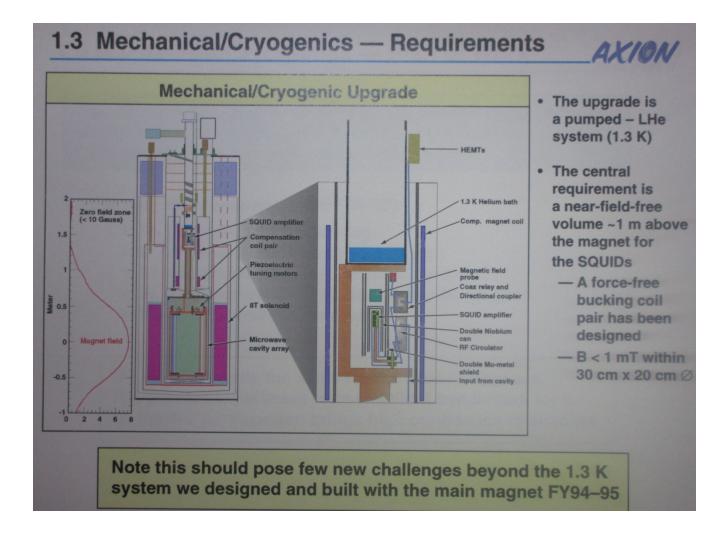


During data taking, we worked on the upgrade, a 4-cavity array for higher frequencies.. We tried out the new piezo driven tuning. There was no room for mechanical gears on the small cavities.

And the tuning rod motion per step is only about 100 atoms! A challenge.



After initial difficulties, the piezo tuning worked. The tuning rods hang directly on drive disc. With 10 nm motions, all material behaves like rubber....



The compensation coil is pushed up with a 5 ton force.

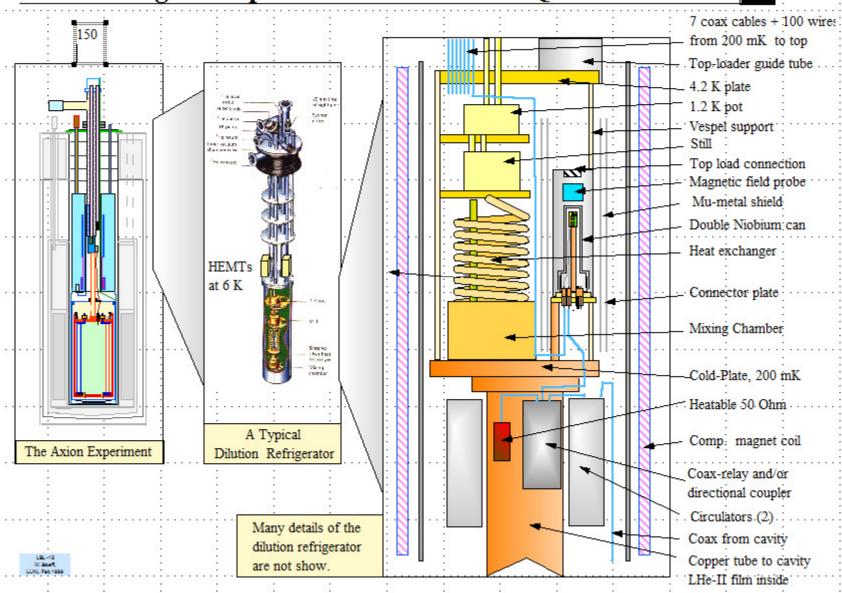
In about 1998, we already had an eye on a squid system. Developed at LBL by Clark and Co.

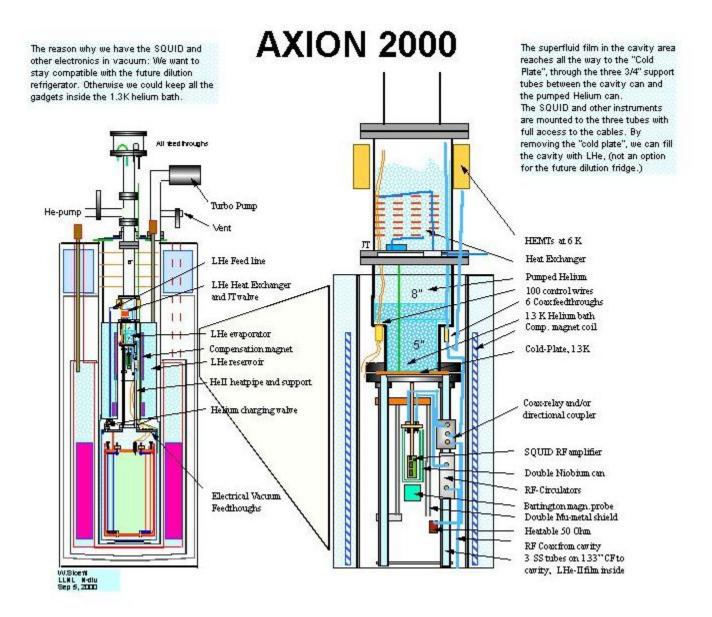
It requires a zero field region just above the 8 Tesla magnet. Stable to femto-Gauss and less than 1 mGauss.

Using A "Top-Loader":

The SQUID Box







We came up with a few ideas how to implement a squid, and later a dilution fridge.

Improvements:

The Cavity Q-factor



Scan rate scales like



Our present single cavity:

100 cm long and 50 cm in diameter.

UBAC ("organic") copper plated stainless steel.

Un-tuned cavity frequency f_{010} scales with diameter:

50cm = 460 MHz

There is no RF-superconducting material at 8 Tesla.

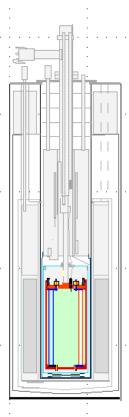
The unloaded cavity Q is about 250,000, close to the theoretically expected value.

The scan rate can be slightly improved by overcoupling the cavity, but need impedance-mismatch tolerant amplifier to do so.

Cavity resonance curve MUST be wider than the Axion signal, otherwise the cavity response function becomes entangled with the Axion signal in a big way.

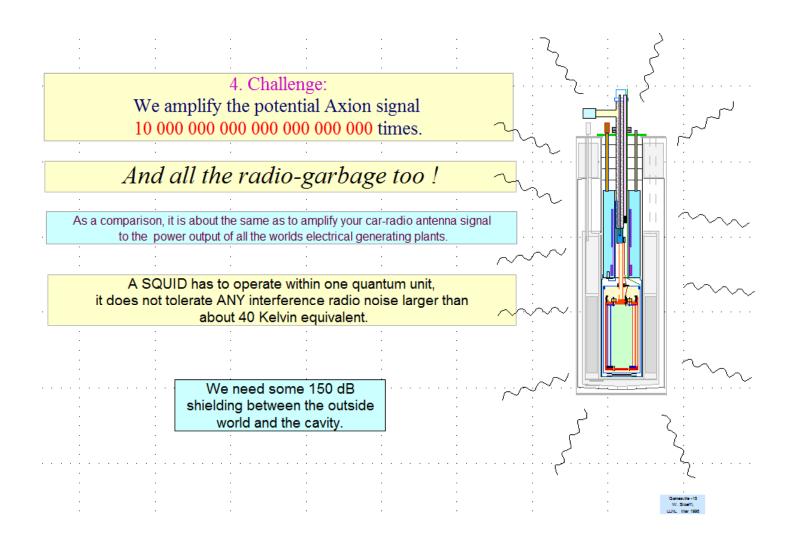
Little improvement possible.

There is a drawback at 250 mK: We can no longer navigate around mode-crossings by submerging the cavity in LHe to shift the modes. 250 liter LHe can not be cooled to 250 mK!





Some more thought we had.



Radio shielding is essential And microphonics shielding.

A Severe Limitation on the Magnet: Eddy Currents



With the present cavity cooling we could tolerate up to 10⁻⁶ Tesla/second field ripple.

Our present magnet (non-persistent) has a field ripple of about 10^{-7} T/s. The powersupply runs stable to \pm 1 mV/min. The coil inductance is 533 Henry.

The Eddy current heating of a future 200 mK cavity is a very severe limitation for the magnet:

dB/dt has to be less than 10⁻⁹ Tesla/second to keep the Eddy current heating of the cavity to less than 100 μW.

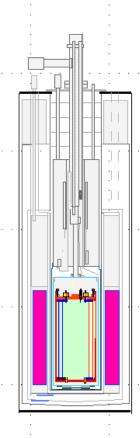
The magnet needs a persistent mode halflife of longer than 300 years.

We have to make the copper plating of the cavity thinner and we have to use LOW RRR copper (<10 RRR) to cut Eddy heating by a factor 100 from the existing cavity.

10-9 T/s is 0.01 milli-Gauss/second!

The average household 60 Hz ripple is 1 mG, or 100 mG/s

We have to shield the experiment from 60 Hz stray-fields!





If one tries to push the limit, nature shows you the limit.....



And quantum noise studies in B282

From neutrinos to Axions....

